2018 EUVL Workshop - P19

Accelerator based extreme ultraviolet (EUV) sources for lithography

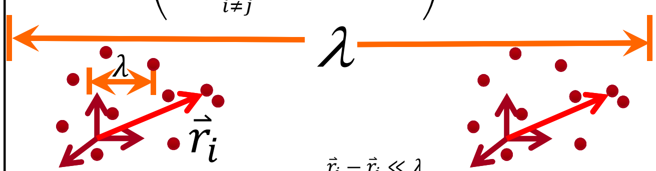
J. Wu† and A.W. Chao*, SLAC National Laboratory, Menlo Park, CA, USA

Abstract: Extreme ultraviolet lithography (EUVL) is a next-generation lithography technology using an extreme ultraviolet (EUV) light source, currently at 13.5 nm. We review a few accelerator based approaches for EUV source generation, including Laser Induced Microbunching (LIM) schemes, High-Gain Inverse Compton (HGIC) source, etc. Besides the high average power required by EUVL; for industrial applications, EUV source's reliability, stability, reproducibility, and repeatability are all important measures. A storage-ring based steady state microbunching (SSMB) configuration (Chao, Int. J. Mod. Phys. A, 2015) is a very promising approach providing EUV source at kilowatts level average power meeting the high throughput requirement for EUVL. A reversible SSMB a promising configuration. The SSMB system size is also carefully designed aiming to be compatible with the lithography tools. Such accelerator baser EUV sources are compared to others approaches, such as laser-produced plasma (LPP) source.

†jhwu@SLAC.Stanford.EDU; *achao@SLAC.Stanford.EDU

Introduction: Coherent and Incoherent

$$I_N \propto I_1\left(N + \sum_{\substack{i=1\\i\neq j}}^{N}\sum_{j=1}^{N} e^{-i\vec{k}\cdot(\vec{r}_i-\vec{r}_j)}\right) = I_{\mathrm{Inc}} + I_{\mathrm{Coh}}$$



$\vec{r}_i - \vec{r}_j \ll \lambda$

$\vec{r}_i - \vec{r}_j \gg \lambda$

$I_N \approx N I_1$

$$I_N \propto I_1\left(N + \sum_{\substack{i=1\\i\neq j}}^{N}\sum_{j=1}^{N} e^{-i\vec{k}\cdot 0}\right) = I_1\left(N + N(N-1)\right) = N^2 I_1$$

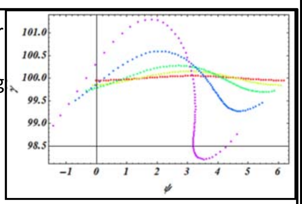
Laser Induced Microbunching

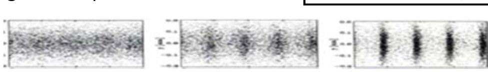
Laser-electron interaction in an undulator

whose dispersion Leads to microbunching

red → yellow → green → blue → cyan

Ginzberg-Landau phase transition

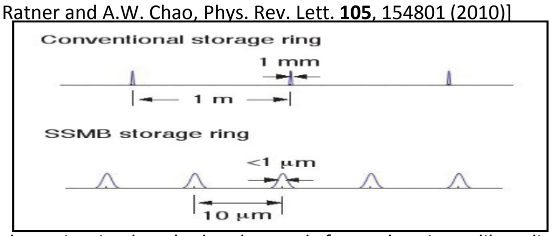




[S.Y. Cai and A. Bhattacharjee, Phys. Rev. A **43**(12), 6934 (1991)]

A New Storage-Ring Light Source

Steady-State Micro-Bunching (SSMB)
[D.F. Ratner and A.W. Chao, Phys. Rev. Lett. **105**, 154801 (2010)]

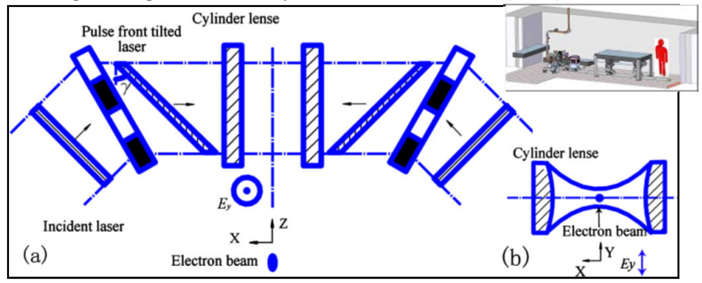


- The beam is microbunched and strongly focused, so it readily radiates at thedesired short wavelength (13.5 nm for lithography) at an appropriate radiator, yielding high peak power $\propto N^2$instead of $\propto N$.
- The beam is microbunched in a steady state in a storage ring, so it radiates every turn with a high repetition rate. With a bunch spacing of 10 μm, the repetition rate is 300 GHz.

[A. Chao, Int. J. Mod. Phys. A **30**(22), 1530051 (2015)]

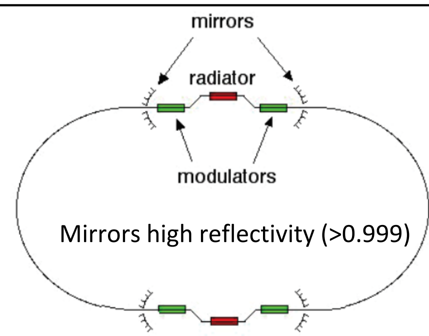
High-Gain Inverse Compton (HGIC) source

High-Gain Thompson-Scattering X-Ray Free-Electron Laser by Time-Synchronic Laterally Tilted Optical Wave
[C. Chang, C. Tang, and J. Wu, Phys. Rev. Lett. **110**, 064802 (2013)]



Extreme Ultraviolet (EUV) Lithography

SSMB



		IR SPEAR3	DUV SPEAR3	EUV dedicated ring	
E_0	beam energy	900	900	580	MeV
C	ring circumference	234	234	100	m
α_C	ring mom. comp. factor	1.9	0.57	0.16	10^{-6}
I_0	average beam current	8.5	4.7	1.12	A
L_m	modulator length	3.7	3.2	3.4	m
λ_m	seed laser wavelength	13.2	3.5	0.37	μm
P_{seed}	seed laser power	15	15.7	11	kW
L_r	radiator length	3.5	3.3	3.54	m
λ_r	SSMB rad. wavelength	0.94	0.205	0.0133	μm
P_r	SSMB rad. power	85	41	4.06	kW

HGIC

	HGIC	Cymer	GigaPhoton	XTREME Tech	HZB/PSI
Type	Research	Commercial	Commercial	Commercial	Research
Technology	HGIC	LPP	LPP	LDP	FEL
Power @ IF (w)	200-5000	~200	15	<10	50k - M
Bandwidth (%)	<0.1	<2	<2	<2	<0.1
Solid Angle (Sr)	0.1	2π	2π	2π	0.1
Brightness (w/mm²sr)	6.0E+06 – 1.5E+08	250	70	20	1.5E+09
Footprint (m)	10	10	10	10	100-1000
Cost (M)	20	15	13	13	>400

Summary and Conclusion

Accelerator based EUV source can provide sufficient power for high-volume manufacturing lithography. Design to fit industrial requirements is feasible; ask for input from lithography tool builders and customers.

The work was supported by the US Dependent of Energy (DOE) under contract DE-AC02-76SF00515 and the US DOE Office of Science Early career Research Program grant FWP-2013-SLAC-100164